



**UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON D.C. 20460**

April 27, 1999

**OFFICE OF
THE ADMINISTRATOR
SCIENCE ADVISORY BOARD**

Note to the Reader:

The attached is a redline/strikeout draft advisory of the Science Advisory Board (SAB). The redline/strikeout draft has been approved by the SAB's Radiation Advisory Committee (RAC) and is being forwarded to the SAB's Executive Committee (EC) for their review and approval. In its present form, it has progressed sufficiently that a significant portion of the text will provide useful information to the reader pertaining to the consensus positions of the Committee in this review. Once approved by the SAB's EC, it will be finalized and transmitted to the EPA Administrator and will become available to the interested public as a final report.

This redline/strikeout draft advisory pertaining to the EPA's proposed methodology for assessing risks from indoor radon based on the National Academy of Science's (NAS) Biological Effects of Ionizing Radiation (BEIR) VI report. It is being released for general information to members of the interested public and to EPA staff. This is consistent with the SAB policy of releasing draft materials only when the Committee involved is comfortable that the document is sufficiently complete to provide useful information to the reader. The reader should remember that this is an unapproved working draft and that the document should not be used to represent official EPA or SAB views or advice. Draft documents at this stage of the process often undergo significant revisions before the final version is approved and published.

The SAB is not soliciting comments on the advice contained herein. However, as a courtesy to the EPA Program Office which is the subject of the SAB review, we have asked them to respond to the issues listed below. Consistent with SAB policy on this matter, the SAB is not obligated to address any responses which it receives.

The SAB's RAC pose the following questions to the Agency staff:

1. Has the Committee adequately responded to the questions posed in the Charge?
2. Are any statements or responses made in the draft unclear?
3. Are there any technical errors?

For further information or to respond to the questions above, please contact:

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AN SAB ADVISORY: ASSESSING RISKS FROM INDOOR RADON

**AN ADVISORY BY THE RADIATION
ADVISORY COMMITTEE ON
PROPOSED EPA METHODOLOGY
FOR ASSESSING RISKS FROM
INDOOR RADON**

**- PUBLIC REVIEW DRAFT -
DO NOT CITE OR QUOTE**

APRIL 27, 1999

(radon7.cln)

April 27, 1999

EPA-SAB-RAC-ADV-99-0XX

Honorable Carol M. Browner
Administrator
U.S. Environmental Protection Agency
401 M. Street, S.W.
Washington, D.C. 20460

Re: Advisory on Proposed EPA Methodology for Assessing Risks from
Indoor Radon Based on BEIR VI: White paper

Dear Ms. Browner:

The enclosed Advisory was developed by the Radiation Advisory Committee (RAC) of the Science Advisory Board (SAB) in response to a request dated February 22, 1999 from Mr. Stephen D. Page, Director of the Office of Radiation and Indoor Air (ORIA) to provide advice on the application in a "White Paper" of the National Academy of Science's (NAS) Biological Effects of Ionizing Radiation Committee report (BEIR VI). In particular, the request to the RAC seeks advice on the following charge questions:

- a) Is the overall approach of using the BEIR VI age-concentration model acceptable?
- b) What advice does the RAC have on the refinements and extensions we (ORIA staff) are considering?, and
- c) Have we (ORIA staff) adequately accounted for the sources of uncertainty?

1 The RAC held a public meeting on March 24, 25, and 26, 1999 at which it
2 was briefed by, and had technical discussions with ORIA staff, as well as a writing
3 session by the Committee. The advisory resulting from these meetings responds
4 both to the three Charge questions briefly discussed below, as well as addressing
5 other issues identified during the public meetings.
6

7 Overall, the Committee was impressed with the quality and focus of the ORIA
8 effort as presented to us in the draft "White Paper." In general, ORIA has proposed
9 a reasonable method for using the National Research Council (NRC)/ National
10 Academy of Sciences (NAS) findings from BEIR VI to form an Agency radon risk
11 model. The authors should be commended for a very thorough effort in considering
12 most aspects of this complex risk assessment. The following comments are
13 intended to help ORIA improve a very good product, and to help ORIA sharpen its
14 approach and communicate its recommendations more clearly. Our response to the
15 charge questions and issues beyond the charge are highlighted and summarized
16 below.
17

- 18 a) Question 1: Is the overall approach of using the BEIR VI age-
19 concentration model acceptable?
20

21 The Committee would prefer a model that provided risk estimates
22 intermediate between those of the concentration and duration models. This
23 preference is bolstered by the predictions of other models discussed in BEIR VI,
24 which also provide intermediate risk estimates. However, the Committee did not
25 arrive at a conclusion regarding the exact method by which this should be
26 accomplished.
27

- 28 b) Question 2: What advice does the RAC have on the refinements and
29 extensions we (ORIA staff) are considering?
30

31 The Committee generally supports the extensions of the BEIR VI models that
32 ORIA proposes to make the EPA radon model most useful for Agency purposes. In

1 particular, the Committee supports expanded treatment of smoking prevalence by
2 age and urges ORIA to continue to investigate how to distinguish between the risks
3 for current smokers and former smokers. The Committee also supports the change
4 of the definition of risk from “excess” to “etiologic” through the inclusion of radon-
5 related lung cancers that would be incurred in persons who would have died later
6 from lung cancer related to other causes. ORIA should also investigate expressing
7 risk in terms of years of life lost, rather than simply counting cases of early mortality.
8

9 c) Question 3: Have we (ORIA staff) adequately accounted for the
10 sources of uncertainty?
11

12 While ORIA has discussed many of the important uncertainties in the radon
13 risk estimates, extending the BEIR VI discussion in some areas and providing
14 quantitative uncertainty estimates for some of the input variables, many of the
15 uncertainties remain unquantified. The White Paper, at this stage of its
16 development, provides little feeling for the overall uncertainties in the risk estimates
17 stemming from all these input uncertainties. The Committee, therefore,
18 recommends additional effort to identify and quantify uncertainties to the extent
19 possible with available resources. Further, identifying the input uncertainties of the
20 risk estimates contributing most to the uncertainties would help in guiding future
21 research.
22

23 d) Beyond the Charge: The need to use the radon risk model for
24 situation-specific assessments.
25

26 The Committee also provided some advice beyond the Charge in Section 4
27 of this advisory. The Agency should be sure that the final radon risk model can be
28 used for situation-specific assessments that require a user-specific mix of sex, age,
29 and smoking status in the studied population. Further, ORIA should provide easily
30 understood tools that would allow the model to be used outside ORIA -- even by the
31 general public -- to estimate radon risks for a variety of situations. However, ORIA
32 should be sure to provide cautions and caveats about the interpretation of risk

1 calculations and about the degree of uncertainty in the modeling procedures.

2
3 The RAC appreciates the opportunity to provide this advisory to you and we
4 hope that it will be helpful. We look forward to the response of the Assistant
5 Administrator for Air and Radiation to the advisory in general and to the specific
6 comments and recommendations in this letter in particular.

7
8 Sincerely,

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10
11
12 Dr. Joan M. Daisey, Chair
13 Science Advisory Board

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15
16
17 Dr. Stephen L. Brown, Chair
18 Radiation Advisory Committee

NOTICE

This report has been written as part of the activities of the Science Advisory Board, a public advisory group providing extramural scientific information and advice to the Administrator and other officials of the Environmental Protection Agency. The Board is structured to provide balanced, expert assessment of scientific matters related to problems facing the Agency. This report has not been reviewed for approval by the Agency and, hence, the contents of this report do not necessarily represent the views and policies of the Environmental Protection Agency, nor of other agencies in the Executive Branch of the Federal government, nor does mention of trade names or commercial products constitute a recommendation for use.

ABSTRACT

On March 24-26, 1999, the Science Advisory Board's Radiation Advisory Committee conducted an advisory for the Office of Radiation and Indoor Air (ORIA) on a White Paper concerning proposed methodologies for assessing risks from indoor radon, which was based on the National Academy of Sciences/National Research Council Biological Effects of Ionizing Radiation (BEIR) VI report.

The Committee found that ORIA has proposed a reasonable method for extending the findings from BEIR VI to form an Agency radon risk model, and made a thorough effort in considering most aspects of this complex task. The comments offered are intended to help ORIA improve a good product, sharpen its approach, and communicate its recommendations more clearly.

A model that would provide risk estimates between those of the concentration and duration models was preferred by the Committee, although an exact method was not proposed. This preference is bolstered by other models discussed in BEIR VI, which yield intermediate risk estimates.

The Committee generally supports modifications of the BEIR VI models intended to improve the usefulness of the EPA radon model, including expanded treatment of smoking prevalence by age and continued investigation on distinguishing the risks of current and former smokers. While ORIA identified and quantified numerous important uncertainties in the radon risk estimates, many still remain unquantified.

The final radon risk model should be made usable for assessments that require specific mixes of sex, age, and smoking status. Further, easily used tools should be provided so that the model can be used outside of ORIA to estimate radon risks for a variety of situations.

KEY WORDS: cancer risks, indoor radon exposures, radon models, radon risk

NOTE TO REVIEWERS: NTIS requires a maximum of 250 words. The revised abstract has approximately 258 words, so we are very close!

U.S. ENVIRONMENTAL PROTECTION AGENCY

**SCIENCE ADVISORY BOARD
RADIATION ADVISORY COMMITTEE
March 24-26, 1999**

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¹ Drs. Poston and Hoel did not attend the RAC's March review meeting. Dr. Poston provided written comments, and Dr. Hoel reviewed the draft advisory after the March meeting.

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1. EXECUTIVE SUMMARY

Radon is well established as a cause of lung cancer in miners (particularly uranium miners) through the inhalation of its radioactive decay products. Radon decay products in indoor air are also widely assumed to cause lung cancer. However, the available epidemiology for residential exposures to radon is ambiguous and does not provide a solid quantitative basis for evaluating the magnitude of the lung cancer risk. As a result, the quantitative analysis of the miner data has been extrapolated from radon decay product exposures in mines to lower residential exposures.

The methods used to perform this extrapolation from mines to indoor air have been debated, however. The National Research Council (NRC) of the National Academy of Sciences (NAS) in March, 1999 released the report entitled "Health Effects of Exposure to Radon" ("BEIR VI") on the risk of indoor radon². The Report discusses several mathematical models capable of making the extrapolation, with an equal preference for two models that produce somewhat different estimates of the population lung cancer burden attributable to indoor radon: the "concentration" model and the "duration" model. Both models also consider the effects of age, sex, and smoking status--never smoker (NS) vs. ever smoker (ES). For the relatively low levels of radon exposure encountered in homes, the concentration model predicts about 40% greater risk per unit of cumulative exposure. Using data on the average levels of radon in homes and the characteristics of the 1995 U.S. population with respect to age, sex, and smoking status, the NRC estimated the cumulative cancer burden (lung cancer deaths per year) from radon in homes with the two models.

EPA's Office of Radiation and Indoor Air (ORIA) is in the process of deciding how to use the NRC findings in its own risk assessments for radon decay products.

²

Whenever the Committee refers to the health effects of radon, the role of the radon decay products is implicit.

1 ORIA must decide whether to adopt one of the two NRC models, to create a hybrid
2 model, to adopt one of the other models discussed by the NRC but not preferred, or
3 to create its own model. If ORIA selects an existing model, it must decide what
4 modifications, if any, are necessary to adapt the model for Agency use. ORIA has
5 produced a “White Paper” (EPA. 1999) discussing the issues of model selection
6 and adaptation and presenting its preliminary conclusions about each issue. It has
7 tentatively chosen to use the concentration model with three important modifications
8 regarding smoking prevalence by age, accounting for radon-related cancers in the
9 national cancer statistics, and identification of premature death in persons who
10 would have later died of lung cancer.

11
12 ORIA requested that the Radiation Advisory Committee (RAC, or “the
13 Committee”) of the Science Advisory Board (SAB) provide advice on its radon
14 modeling efforts by answering three charge questions. The Committee’s responses
15 to the questions appear in Section 3 of this Advisory and are summarized below. In
16 general, ORIA has proposed a reasonable method for using the NRC findings to
17 form an Agency radon risk model. The authors should be commended for a very
18 thorough effort in considering most aspects of this complex risk assessment.

19
20 **1.1 Question 1. Is the overall approach of using the BEIR VI age-**
21 **concentration model acceptable?**

22
23 The Committee believes that the differences in the two primary BEIR-VI
24 models would have vanished if the NRC had used a continuous rather than a
25 discretized representation of radon exposure rates, durations of exposure, and
26 cumulative exposures. Therefore, the ORIA rationale for choosing the
27 concentration model on the basis of biological plausibility and simplicity of use is not
28 compelling. Because we believe that the differences are due solely to the choice of
29 exposure rate and duration increments, we would prefer a model that provided risk
30 estimates intermediate between those of the concentration and duration models.
31 This preference is supported by the predictions of other models discussed in BEIR
32 VI, which also provide intermediate risk estimates. The Committee did not arrive at

1 a conclusion regarding the exact method by which this should be accomplished.
2 The Agency, at a minimum, should examine the strengths and limitations of the
3 categorizations within each model and develop a rationale and consensus on which
4 categories and ranges should be chosen.
5

6 **1.2 Question 2. What advice does the RAC have on the refinements and**
7 **extensions we (ORIA staff) are considering?**
8

9 The Committee generally supports the modifications to the BEIR VI models
10 that ORIA proposes to make the EPA radon model most useful for Agency
11 purposes. In particular, we support the expanded treatment of smoking prevalence
12 by age and urge ORIA to continue investigating how to distinguish between the
13 risks for current smokers and former smokers. We also support the change of the
14 definition of risk from “excess” to “etiologic” through inclusion of radon-related lung
15 cancers that would be incurred in persons who would have died later from lung
16 cancer related to other causes. ORIA should also investigate expressing risk in
17 terms of years of life lost, rather than simply counting cases of early mortality.
18

19 **1.3 Question 3. Have we (ORIA staff) adequately accounted for the sources**
20 **of uncertainty?**
21

22 ORIA has discussed many of the important uncertainties in the radon risk
23 estimates, extending the BEIR VI discussion in some areas and providing
24 quantitative uncertainty estimates for some of the input variables. However, many
25 of the uncertainties remain unquantified, and the White Paper at this stage of
26 development provides little feeling for the overall uncertainties in the risk estimates
27 stemming from all these input uncertainties. The Committee, therefore,
28 recommends additional effort to identify and quantify uncertainties to the extent
29 possible with available resources. Although we recognize the difficulties of such an
30 effort, some guidance on the overall reliability of the estimates would be welcome.
31 Identifying the input uncertainties contributing most to the uncertainties in the radon
32 risk estimates would help in guiding future research. Most important, it would

1 provide the public with an indication of the uncertainties associated with prediction
2 of radon-caused lung cancer deaths.

3 4 **1.4 Beyond the Charge**

5
6 The Committee also provided some advice beyond the Charge as presented
7 in Section 4. In brief, the Agency should be sure that the final radon risk model can
8 be used for situation-specific assessments that allow for a user-specified mix of sex,
9 age, and smoking status in the population of concern. Further, it should provide
10 easily understood tools that would allow the model to be used outside ORIA--even
11 by the general public--to estimate radon risks for a variety of situations. However,
12 ORIA should be sure to provide cautions and caveats about the interpretation of risk
13 calculations and about the degree of uncertainty inherent in the modeling
14 procedures and results.

2. INTRODUCTION

2.1 Background

Radon is well established as a cause of lung cancer in miners (particularly uranium miners) through the inhalation of its radioactive decay products (“radon progeny”). The epidemiologic evidence from studies of miners is supported by results from animal studies and radiobiological data. Radon decay products in indoor air are also widely assumed to cause lung cancer. The available epidemiology for residential exposures to radon is ambiguous. Although a meta-analysis of a group of residential studies does provide some support for the assumption that radon in indoor air contributes to the risk of lung cancer (Lubin and Boice. 1997), these studies do not provide a solid quantitative basis for evaluating the magnitude of the lung cancer risk. As a result, the quantitative analysis of the miner data has been extrapolated from mine exposures to lower residential exposures.

The methods used to perform this extrapolation from mine air to indoor air have been debated, however. The National Research Council (NRC) of the National Academy of Sciences in March, 1999 released the report “Health Effects of Exposure to Radon” (“BEIR VI”) on the risk of indoor radon³. The report discusses several mathematical models capable of making the extrapolation, with an equal preference for two models that produce somewhat different estimates of the population lung cancer burden attributable to indoor radon. One model, the “concentration” model, uses the average level of exposure (in working levels - WL) along with cumulative exposure (in working level-months - WLM) to predict risk, while the other, the “duration” model, uses duration of exposure (in years) along with WLM. Both models also consider the effects of age, sex, and smoking status-- never smoker (NS) vs. ever smoker (ES). For the relatively low levels of radon

³ Whenever the Committee refers to the health effects of radon, the role of the radon decay products is implicit.

1 exposure encountered in homes (generally much less than 0.5 WL), the
2 concentration model predicts about 40% greater risk per unit of cumulative
3 exposure. Using data on the average levels of radon in homes and the
4 characteristics of the 1995 U.S. population with respect to age, sex, and smoking
5 status, the NRC also estimated the cumulative cancer burden (lung cancer deaths
6 per year) from radon in homes with the two models.

7
8 EPA's Office of Radiation and Indoor Air (ORIA) is currently in the process of
9 deciding how to use the NRC findings in its own risk assessments of radon. ORIA
10 must decide whether to adopt one of the two NRC models, to create a hybrid model,
11 to adopt one of the other models discussed by the NRC but not preferred, or to
12 create its own model. If ORIA selects an existing model, it must decide what
13 modifications, if any, are necessary to adapt the model for Agency use. ORIA has
14 produced a "White Paper" discussing the issues of model selection and adaptation
15 and presenting its preliminary conclusions about each issue (EPA. 1999). It has
16 tentatively chosen to use the concentration model, modified to account for the
17 following:

- 18 1. age-specific smoking prevalence data;
- 19 2. early deaths in people who would later have died from lung cancer not
20 associated with radon; and
- 21 3. an adjustment to remove radon-attributable cancer deaths from the
22 baseline lung cancer risk derived from national cancer mortality
23 statistics so that the application of the relative risk concentration
24 model will be consistent.

25 ORIA is also extending the uncertainty analyses provided in the BEIR VI report.
26

27 After considering the comments in this Advisory and perhaps from other
28 observers, ORIA will produce one or more reports similar to the "Blue Book" (EPA.
29 1994) that will describe its radon risk methodology and its application to various
30 problems.

31 32 **2.2 Charge to the SAB**

1 ORIA has requested that the Radiation Advisory Committee (“the
2 Committee”) of the Science Advisory Board (SAB) provide advice on its radon
3 modeling efforts by answering the following three charge questions:
4

5 Question 1. Is the overall approach of using the BEIR VI age-concentration model
6 acceptable?
7

8 Question 2. What advice does the RAC have on the refinements and extensions
9 we (ORIA staff) are considering?
10

11 Question 3. Have we (ORIA staff) adequately accounted for the sources of
12 uncertainty?
13

14 On February 22, 1999, Mr. Stephen D. Page, Director of the Office of
15 Radiation and Indoor Air (ORIA) requested an advisory of Dr. Donald G. Barnes,
16 Director of the Science Advisory Board (SAB) on a “white paper” outlining proposed
17 revisions to EPA’s current methodology for assessing risks from indoor radon in
18 light of the National Academy of Science’s (NAS) “Health Effects of Exposure to
19 Radon” Biological Effects of Ionizing Radiation Committee report (BEIR VI). The
20 RAC engaged in the advisory at its March 24-26, 1999 public meeting. The
21 Committee prepared the initial draft advisory during the March public meeting. In
22 the course of the review, the Committee also identified other issues beyond the
23 charge. These issues deal principally with uses and documentation of the EPA
24 radon model.

3. RESPONSE TO THE CHARGE

In general, ORIA has proposed a reasonable method for using the NRC findings to form an Agency radon risk model. The authors should be commended for a very thorough effort in considering most aspects of this complex risk assessment. The following comments are intended to help ORIA sharpen its approach and communicate its recommendations more clearly.

3.1 Question 1: Is the overall approach of using the BEIR VI age-concentration model acceptable?

The Committee is generally supportive of ORIA's proposal to select one of the BEIR VI models (or a hybrid) rather than maintaining two separate models for future analyses. Use of both models could well cause confusion among those outside the scientific community. Based on information presented in BEIR VI and the White Paper, the estimates of the U.S. lung cancer burden due to residential radon are somewhat different when using the concentration model vs. the duration model--both of which are methods for taking into account the inverse exposure rate effect. The concentration model appears to be more conservative in the sense that it estimates approximately 40% more annual deaths nationwide, a difference that might be politically significant even if not statistically significant. ORIA needs to consider the importance of such a perceived difference.

While ORIA has presented two arguments to support its selection of the concentration model over the duration model for a variety of risk assessment purposes, neither argument is unassailable. The argument based on biological plausibility assumes that radon acts principally as an initiator of cancer. The possibility that radon has cancer promoting activity (e.g., through cell killing and subsequent cell proliferation) should not be dismissed. The argument based on simplicity falters if exposure rate is interpreted as average radon decay product concentrations (working levels) over an extended duration of exposure, as it

1 appears the NRC used for each miner in its epidemiologic evaluation.

2
3 The estimates from both risk models seem to depend on the cut points
4 selected for exposure and exposure rate in the analysis of the miner data. If the cut
5 points had been selected differently, both the concentration and duration models
6 could have yielded different results. A model such as the Cox proportional hazards
7 model (Cox. 1972) can be constructed incorporating both cumulative exposure and
8 either exposure rate or duration as continuous variables representing different
9 aspects of protracted exposure. The choice between the latter variables should
10 yield identical likelihoods, due to the fact that cumulative exposure in WLM is simply
11 the product of intensity of exposure (measured in WL) and duration of exposure in
12 months. Therefore, the use of multiplicative relative risk models, such as those
13 used in BEIR VI, means that inclusion of either duration or concentration makes the
14 other unnecessary. The primary reason that the BEIR VI concentration and
15 duration models differ in their estimates of the overall risks appears to be that each
16 of these variables was categorized independently and their product is not
17 necessarily equal to cumulative exposure.

18
19 The rationale in the White Paper for choosing the concentration model,
20 therefore, becomes arbitrary. We have already questioned the biological argument
21 and the simplicity argument. Orally, ORIA also offered the argument that the
22 concentration model would be more easily understood by the general public.
23 Although the argument has some merit, it is in itself not a compelling reason to
24 choose the concentration model to represent the inverse dose-rate effect.

25
26 Given the potential political pitfalls of appearing to choose a model simply to
27 estimate risk conservatively, it may be prudent to consider using a model that
28 produces estimates intermediate between the concentration and duration models.
29 For example, the constant relative risk (CRR) model fitted to miners with relatively
30 low exposures or the meta-analysis model of the residential studies, both estimated
31 in BEIR VI, produce risk estimates greater than the duration model but less than the
32 concentration model. Both of these models are also appealing since they represent

1 exposures more relevant to the indoor radon problem. However, the Committee
2 recognizes that the latter models do not include coefficients that modify risk for
3 attained age and time since exposure, which reduces their appeal for estimating risk
4 using the EPA lifetable approach. Rather than recommend a specific model for use
5 by EPA, the Committee prefers to defer the final model choice to EPA, with the
6 recommendation that the weight of evidence seems to indicate that the most
7 accurate estimates are between those produced by the duration and concentration
8 models.

9
10 The Committee notes that cancer risk theory predicts differing risks for the
11 same cumulative exposure depending on the timing and pattern of exposure, with
12 the direction of the differences depending on the mechanism of carcinogenesis
13 (e.g., initiation vs. promotion). As proposed, the concentration model is probably
14 better at dealing with time-varying exposures than are the other proposed models,
15 but all are deficient in some respect and further research in this arena would be
16 useful. The use of average exposure rates over periods of time in WLM/month may
17 have caused some bias in the radon risk estimates. If the variation in the estimated
18 average exposure rates was randomly distributed about the true exposure rates in
19 each mine, the bias would be toward lower risks⁴. If the variation was systematic
20 (e.g., exposure rates declining with time for most miners), the bias might be in the
21 other direction.

22 23 24 **3.2 Question 2: What advice does the RAC have on the refinements and** 25 **extensions we (ORIA staff) are considering?**

26 27 **3.2.1 Overview**

28
29 The proposed methodology for calculating radon risk described in the White

⁴ BEIR VI actually did use time-varying exposures by calculating each miner's cumulative exposure at specific age intervals. Bias toward the null would occur if WLM estimates were unbiased but subject to random misclassification.

Paper is very sophisticated (EPA. 1999). It builds upon the BEIR VI report conclusions (NRC. 1998). The White Paper takes the information about radon risk that was developed by the NRC and puts it into a form that can be used by the EPA for a variety of purposes including, but not limited to, updating its public information aimed at reducing residential radon exposures. For instance, ORIA improved the usefulness of the radon risk estimate by the inclusion of smoking patterns from the data supplied by the Department of Health and Human Services.

The refinements EPA has used in deriving the risk numbers appear to be reasonable, although in light of the level of uncertainty in the basic model at low radon concentrations, some of these refinements may have little effect on the effective range of the risk estimates. However, the Committee found it difficult to determine how much of the increase in estimated cases of lung cancer in the US between the 1992 EPA estimate and the various examples given in the White Paper is due simply to the increase in size and change in composition of the population on which the risk is projected, and how much of the increase is due to increased risk per person.

3.2.2 Baseline Adjustment

The Committee had difficulty understanding ORIA's adjustment to the baseline risks to account for the contribution of radon to the current lung cancer statistics. The Committee agrees that ORIA is correct to avoid double counting of risks in the relative risk approach. However, when the adjustment is applied, it effectively makes the baseline cancer rates applicable to a hypothetical population exposed to a radon level of zero in the home. It does not correct for the ambient (outdoor) radon level. Because no population exists with a zero exposure to radon, the results are difficult to understand, interpret, and communicate. It would be easier to understand a baseline adjustment consistent with the state of the art in radon mitigation, which would bring the radon level in residences to a credible but non-zero level.

3.2.3 Smoking Patterns

The Committee strongly supports an ORIA effort to incorporate a category for former smokers. The general U.S. population has a higher prevalence of former smokers than in the 11 cohorts of miners used in the BEIR VI report. Also, the relative risk for lung cancer due to smoking declines with time from cessation of smoking. This decrease should be reflected in lower numbers of excess lung cancers if these estimates are used in ORIA's life table approach. This approach has the added benefit of demonstrating to the public that the best strategy includes reducing indoor radon levels as well as eliminating or reducing cigarette smoking.

EPA proposes to add a discussion on how changes in smoking patterns might impact estimates of risk. It is even more important to discuss how changes in radon exposure through the installation of a mitigation system could affect risk.

3.2.4 Etiologic Definition

The Committee supports ORIA's proposal to shift from an "excess" definition of risk to an "etiologic" definition by including radon-induced lung cancers that occur in persons who would have died of lung cancer (from other causes) later on.

It is interesting that for the example of the female NS (page 15, Fig.3), virtually all of the lung cancer mortality for ages up to 50 to 55 years is attributable to radon. There is a school of thought that years of life lost, or even quality-weighted years of life lost, is a more appropriate parameter with which to gauge detriment than is simply the number of premature deaths. With this in mind, the apparent fact that lung cancer deaths attributable to radon begin 10 - 15 years earlier than those from remaining causes should perhaps be highlighted. Certainly, the Committee supports the presentation of the radon risk as the probability of dying prematurely from a radon-induced lung cancer.

3.3 Question 3: Have we (ORIA staff) adequately accounted for the sources

of uncertainty?

Although the discussion of uncertainties is a good start and many of the sources of uncertainty are adequately treated, some sources of uncertainty and their importance have not been adequately discussed. For example, the results of the Cohen study are dismissed using the arguments that ecologic studies are not valid for establishing causation (due to possible confounding), and also that the results are biologically implausible and inconsistent with residential case-control studies. Cohen (Cohen, 1990) has attempted to account for confounding by smoking and other factors to the extent possible using population data. The RAC recognizes that ecologic studies have a limited ability to address confounding, because data on individuals are not available; however, the results of such studies should be acknowledged in a discussion of uncertainties. At low exposure levels, the case-control studies, in general, seem to show very little effect. Finally, the assertion of biological implausibility ignores the possibility that at low levels, radiation may stimulate the immune system (hormesis). Although the Committee is not advocating the hormetic hypothesis or other threshold or nonlinear exposure-response relationships, from the evidence now available, a threshold exposure (i.e., a level of exposure below which radon has no effect) cannot be excluded. Therefore, we believe the White Paper should acknowledge in its uncertainty assessment the possibility that radon may not increase lung cancer risks at very low levels of exposure.

More discussion would also be useful on the uncertainties attributable to potential misestimation of miner's exposures, and on how changes in smoking patterns or cigarette composition would affect calculated risks. With respect to miner's exposures, not only are there errors in average exposure estimates (which may cause bias, as noted in the White Paper), but individuals with the same average exposure may have different timing of exposure, and hence different lung cancer risks. Moreover, the relevance of the Chinese cohort data seems questionable, for a variety of reasons. Finally, susceptibility due to either genetic or environmental factors might be different in miners than in the general population,

1 and this possibility contributes to uncertainties in the residential risk estimates.

2
3 With respect to smoking patterns, there is great variability between
4 occasional and heavy smokers. Although the Committee realizes that it may not be
5 possible to factor this variability into the model, perhaps data are available to at
6 least characterize the extent of variability in smoking patterns. There is also
7 uncertainty about the relative risk of radon for former smokers, and about radon
8 risks to passive smokers. Finally, differences in lung dose per WLM exposure could
9 vary by age, sex, and smoking status.

10
11 As other examples, reductions in radon exposure not only will change the
12 distribution of exposures used in the cancer burden estimates, but may also require
13 the adjustment in the risk coefficients that account for the contribution of the
14 baseline radon exposure to observed lung cancer rates. Moreover, if the
15 equilibrium fraction for radon progeny correlates with the radon level in homes,
16 residential risk estimates would be affected.

17
18 It is extremely important that the sources of uncertainty be discussed in some
19 detail so that the reader can understand the assumptions made in the model, the
20 range of possible values for each parameter, and the impact of these uncertainties
21 on the resulting estimates. Although the Committee realizes that quantification will
22 often be difficult if not impossible, ORIA should attempt a sensitivity analysis to
23 identify which of the input uncertainties contribute most to the overall uncertainties
24 in the risk estimates.

25
26 Finally, although uncertainty is discussed in Section VI, statements of
27 uncertainty are not provided in the rest of the document. While it is clear that the
28 numbers in the White Paper are for illustration only and do not represent EPA policy
29 at this time, qualitative expressions of uncertainties should be associated with
30 numerical estimates in any future descriptions or applications of this methodology
31 that are intended for broader distribution.

4. COMMENTS BEYOND THE CHARGE

4.1 Uses of the EPA Radon Model

Although the White Paper provides several examples of uses to which the radon risk model could be put, its only numeric example is an estimate of the lung cancer burden (deaths per year) attributable to residential radon. Much of the discussion of model choice and modifications seems to focus on this use. However, the models will undoubtedly be used for situation-specific assessments as well, with possibly even more important policy implications. It therefore seems desirable to provide the users with the ability to input their own mix of sex, age, and smoking status, rather than to have them be forced to use the national mix at some specific point in time.

However the risk model is finally formulated, it would be desirable for ORIA to provide tools that would allow it to be used outside ORIA--even by the general public--to estimate radon risks for a variety of situations. The tools should be easy to understand and use, but they should be accompanied by cautions about the interpretation of risk calculations and about the degree of uncertainty inherent in the modeling procedures and their results to minimize the potential for misuse of the risk estimates. Guidance should be provided on uses of the models that would be inappropriate or misleading.

4.2 Documentation of the Model

The White Paper is generally quite readable for an audience familiar with the radon risk literature. However, it assumes a high level of expertise and familiarity with BEIR VI that would not be found in most audiences. When ORIA produces its official risk assessment methodology report, more detailed explanations should be provided, especially on those issues where EPA's approaches are substantial extensions of those of BEIR VI. Further, explanations need to be clearer and better

1 justified, especially concerning why EPA chose the “concentration” versus the
2 “duration” model, as well as the methodology for adjusting baseline lung cancer
3 death rates for the existing distribution of residential radon levels. The latter
4 concept seems to have been made more difficult than necessary, and several of the
5 Committee members were confused by the discussion. Although it does not appear
6 that the White Paper itself will be distributed widely, it will be important to keep
7 these points in mind to the extent that this document serves as the basis for later
8 documents and as a reference for health professionals in communicating with the
9 public. Moreover, derivation of some of the equations used would be helpful to the
10 critical reader. For example, equation (4)--determination of lung cancer rates for
11 non-smokers from population lung cancer rates--would be clearer if a short
12 derivation were included either in the text or as an appendix.

13
14 The quantity “exposure rate” and its units are not used consistently in the
15 document. In Table 2, and on page 14 (Section 3b), the units for exposure rate are
16 WL; however, on page 13, in an example used to bolster arguments against the
17 duration model, exposure rate is expressed in WLM/y. Furthermore, ORIA needs to
18 clarify that the actual quantity used in BEIR VI is WLM/ month, not the
19 instantaneous concentration as expressed by WL. A related question regards the
20 duration model. If exposure rate is expressed in WL, are comparisons between
21 exposures in mines and dwellings with this model comparable, given that occupancy
22 times for mines (~24%) and dwellings (assumed to be 70%) differ by nearly a factor
23 of three? Equal radon decay product concentrations in mines and dwellings will
24 lead to quite different average exposure rates when the averages are taken over a
25 day or more.

26
27 The definitions of smoking status (ever smoker, never smoker, and former
28 smoker) need to be sharpened to avoid ambiguity. Number of cigarettes smoked
29 daily or in total, duration of smoking, age at first smoking, and time since cessation
30 of smoking could be used to define the categories. Moreover, the uncertainties
31 introduced by these category definitions need to be discussed. Using only two or
32 three categories for a continuum of behavior introduces the same kinds of

1 difficulties as defining the increments of age or exposure rates used in the risk
2 equations. How should “passive” smokers (e.g., children or spouses of heavy
3 smokers) be classified?
4

5 Although the title and the Introduction clearly state that the White Paper is
6 intended to address methodology, the document ends abruptly. Perhaps the fact
7 that this is just methodology should be recapped at the end, and there should be a
8 paragraph or two that says what EPA will do next. The three uses of the
9 methodology as outlined in the Introduction should be repeated and expanded upon
10 there.
11

12 After releasing its methodology report, a next step would be to prepare a
13 paper for a peer-reviewed journal such as *Health Physics*. This Committee has
14 recommended previously that EPA be more active in their activities within the
15 radiation protection societies. EPA can gain much credibility by making the
16 radiation safety professionals more aware of these solid scientific contributions.
17

APPENDIX A- DETAILED COMMENTS

A- 1 Comments on Units , Terminology, Tables, and Figures

- a) The Uncertainty Analysis section of the White Paper refers to “errors in dosimetry.” These are not really errors in dosimetry, but errors in exposure estimates.
- b) On page 3: There needs to be more of an explanation of Working Level. How does it equate to pCi/L?
- c) Be sure all details such as units, etc. are given in Tables and Figures to make these self-explanatory.
- d) Tables and figures need to be labeled more clearly...for example, where table titles say “number”, the symbol # or the word “number” should also appear immediately adjacent to the appropriate column or row. Every attempt should be made to facilitate a reader’s correct and timely interpretation of the tables.
- e) The risk estimates in Table 7 should be multiplied by 10^{-4} .

A- 2 Recommendations for Clarifying the Report

- a) The inclusion of Appendix A in the middle of the text was also a bit confusing. It was not clear whether that was intentional or an artifact of the word processing.
- b) In Section D, it is stated that the NAS preferred models are applicable

1 to any population. Is this really the case? What about populations
2 with compositions different from the US average? Populations within
3 the U.S. may differ substantially in age and sex distribution, smoking
4 prevalence, race or ethnicity, and other factors potentially influencing
5 risk.

6
7 c) On page 6, more explanation for the value of 0.9, by which β is
8 adjusted downward, would be useful.

9
10 d) On page 26, the basis for assuming a constant rate of change is not
11 explained. Given only two data points from which to extrapolate, a
12 linear extrapolation might just as well be postulated. Having decided
13 to do a constant rate of increase projection, a formula for the more
14 general case should be given, rather than just a numerical example. It
15 could take the form:

16

$$P(y) = P(y_0) \cdot \left(\frac{P(y_1)}{P(y_0)} \right)^{(y-y_1)}$$

17 Moreover, exactly how the prevalence rates were adjusted downward
18 “to be in agreement with estimates from the OSH” is not clear.

19
20 e) On page 32 (Section C2), the White Paper states that the rate of lung
21 cancer in females is approaching that in males. However, female lung
22 cancer mortality rates are still less than one half those of males. (EPA.
23 1994).

24
25 f) On page 4, more explanation of why the “inverse dose rate” effect
26 makes biological sense is needed.

27
28 g) On page 3 (paragraph 2), the statement that “...the right hand side...is
29 multiplied by a factor K...” requires further explanation/justification.

- h) On page 3 (paragraph 3), some explanation of “...life table techniques...” would be helpful: how they are used, why it makes sense to use them here. This could be done in a footnote.
- i) On page 3 (paragraph 3), the White Paper states that the methodology “...subtracted off the estimated radon-induced lung cancer deaths...” Further explanation is needed.
- j) On page 5 (paragraph 1), the White Paper states that “...the dose to target cells...was typically about 30% lower for a residential exposure as compared to an equal WLM exposure in mines.” Some additional (short) explanation of how NAS reached this conclusion would be helpful (e.g., footnote, appendix, etc.).
- k) On page 6 (paragraph 2), the White Paper states that attributable risk “... is only weakly dependent on lung cancer rates.” Why?
- l) On page 9 (paragraph 1), the White Paper states that “...BEIR VI did not provide numerical estimates of the risk per WLM.” This is an important point. Why did BEIR VI decide not to do this? Was it beyond their charge? Did they feel that the information was too weak to support such a move? A word of explanation as to why EPA needs to do this would be important.
- m) On page 13 (paragraphs 3-4) the White Paper states that “...we prefer the concentration model...” The White Paper needs to provide more than the two-paragraph explanation currently devoted to this--perhaps some discussion of the likely convergence of the 2 models would be helpful. How different are the results of these 2 models likely to be?
- n) On page 19 (paragraph 1), the White Paper contrasts “AR” and “... the risk per WLM ...” There are several epidemiologic approaches

1 used in the document, which makes the document confusing. Perhaps
2 a glossary with a brief discussion of how each is used and which is the
3 most pertinent/revealing for this discussion would be helpful (or just
4 making the text clearer regarding the utility of each measure).
5

6 o) On pages 30-31, the discussion of uncertainties in miner data is nicely
7 done. However, the Committee members were not all familiar with
8 “submultiplicative” (page 31, paragraph 4) as a scientific term.
9

10 p) On page 9, please explain item 2.
11

12 q) On page 13 (paragraph 3), this discussion could be strengthened with
13 reference to observations of an inverse dose rate effect in experiments
14 with alpha emitters in laboratory animals. However, observations at
15 high exposure levels do not necessarily imply similar behavior in the
16 residential radon exposure range. In the proposed model, risk per
17 WLM does not increase further below 0.5 WL. The possibility that the
18 increase could either continue or reverse should be discussed in the
19 uncertainties section. The relationship between the inverse dose rate
20 effect and dose or dose rate could be discussed.
21

22 r) On page 32 (Section 2), could there be a difference in dosimetry
23 between males and females?
24

25 s) The assumption of few new smokers after age 21 should be
26 documented.
27

28 t) On page 33 (paragraph 2), what about the relatively short life-spans of
29 the Chinese miners?
30

31 u) On page 34 (last paragraph), the Committee recollects that in some of
32 the animal experiments cited, radon and smoking exposures generally

1 occurred on the same day in both groups (smoking followed by radon
2 or vice versa). If this is the case, then they would not be very relevant
3 for assessing the relative susceptibility of children to radon if they
4 became smokers many years later. ORIA should check this point.
5

APPENDIX B- DETAILED EDITORIAL COMMENTS

- a) On page 2, the citation (NAS, 1990) is not in the references. Should it be NAS (1988)?
- b) On page 14, “0.69 for $a \leq 75$ y” should be “0.69 for $a \geq 75$ y”.
- c) On page 29 (paragraph 2), the White Paper states that “...the committee’s preferred uncertainty estimates were obtained from the CRR model.” This model should have been introduced earlier in the document as another model with which EPA staff does not agree.
- d) On page 10 (next to last line), should this be $h^{pop}(a)$?
- e) On page 29 (line 2), omit one “these.”
- g) On page 32 (line 2), the statement should say “There are very few data”.

APPENDIX C- GLOSSARY OF TERMS AND ACRONYMS

ADV	<u>A</u> dvisory
BEIR	<u>B</u> iological <u>E</u> ffects of <u>I</u> onizing <u>R</u> adiation
Ci	<u>C</u> urie
CRR	<u>C</u> onstant <u>R</u> elative <u>R</u> isk
EPA	U.S. <u>E</u> nvironmental <u>P</u> rotection <u>A</u> gency (U.S. EPA, EPA, or “the Agency)
ES	<u>E</u> ver <u>S</u> moker
L	<u>L</u> iter
NAS	<u>N</u> ational <u>A</u> cademy of <u>S</u> ciences
NRC	<u>N</u> ational <u>R</u> esearch <u>C</u> ouncil
NS	<u>N</u> ever <u>S</u> moker
ORIA	<u>O</u> ffice of <u>R</u> adiation and <u>I</u> ndoor <u>A</u> ir (U.S. EPA)
p	<u>P</u> ico (one trillionth, e.g., 10^{-12} Ci is a picocurie)
RAC	<u>R</u> adiation <u>A</u> dvisory <u>C</u> ommittee (of the U.S. EPA/SAB/RAC)
SAB	<u>S</u> cience <u>A</u> dvisory <u>B</u> oard (of the U.S. EPA/SAB)
U.S.	<u>U</u> nited <u>S</u> tates
vs	Versus
WL	<u>W</u> orking <u>L</u> evels
WLM	<u>W</u> orking <u>L</u> evel- <u>M</u> onth
y	Year

REFERENCES

1. Cohen, B.L.. 1990. "A Test of the Linear-No Threshold Theory of Radiation Carcinogenesis," *J. Environ. Res.* 53:193-220
2. Cox, D.R.. 1972. "Regression Models and Life Tables," *J. Royal Stat. Soc.*, Series B, 34:187
3. Environmental Protection Agency. 1999. Proposed EPA Methodology for Assessing Risks from Indoor Radon Based on BEIR VI. Office of Radiation and Indoor Air, February Draft
4. Environmental Protection Agency. 1994. Revised Methodology for Estimating Radiogenic Cancer Risks, EPA 402-R-93-076, June (EPA Blue Book)
5. Landis, S. H., T. Murray, S. Bolden, T.A. Wingo. 1998. Cancer Statistics, 1998. *CA (A Cancer Journal for Clinicians)*, Vol. 48, No. 1, pp. 6-29
6. Lubin, J. H., and J. D. Boice. 1997. Lung cancer risk from residential radon: meta-analysis of eight epidemiologic studies. *J. Natl. Cancer Inst.* 89:49-57
7. National Research Council. 1998. Health Effects of Exposure to Radon. Natinoal Academy Press, BEIR VI, Washington, DC. (Prepublication Copy), Thursday, February

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